SEISMICITY OF CENTRAL ASIA AS OBSERVED ON THREE IMS STATIONS

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ABSTRACT

Four months of interactive seismic data analysis were conducted to describe the station characteristics of three International Monitoring System (IMS) seismic stations (MKAR, SONM, and BVAR) located in central Asia. Specific study objectives included the location of all local and regional seismic events observed on the three stations, including single station events; identification of seismic sources routinely observed at each station; background noise characterization; identification of any biases in station azimuth, time, and slowness, etc. Additionally, these data provided a baseline for a separate study for evaluation, tuning, and enhancement of automatic and interactive processing functions at the International Data Centre (IDC). During this project, notes were kept on the thresholds necessary at each station for a given event to be recorded at one of the other stations, trends in azimuth and velocity, and any timing errors.

A total of 120 days of data were reviewed (July 20–October 17, 2006; January 1–30, 2007). Over 9,000 events with at least one of the three stations at an epicentral distance less than 20° were human-analyst reviewed, including phase identification and event location. About six percent of the located events included arrival times from all three stations, while about 16% included data from at least two stations. Thirty-nine event clusters, based on geographic and temporal distribution, were identified. The three stations MKAR, SONM, and BVAR are all high-quality seismic arrays. Noise levels at the stations are generally acceptable for the period reviewed, except during the following conditions: (1) a 4.5-Hz intermittent noise source at MKAR, (2) periodic high-frequency bursts on portions of the SONM array, and (3) a monochromatic ring occasionally observed on BVAR. Trends in observed biases were catalogued for each station based on azimuthal distribution. The biases for each cluster were determined by averaging residuals for each measurement (time, azimuth, velocity) and comparing them with the iasp91 travel-time tables routinely used during production of the Reviewed Event Bulletin (REB). Seasonal variation of background noise observed at MKAR had some impact during analysis of the second dataset. Following completion of analysis of the second dataset, measures of the same residuals were conducted and examined relative to the values obtained from the first dataset.

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OBJECTIVES

The objective of this study was to interactively review several months of seismic data from three IMS seismic stations (MKAR, SONM, and BVAR) located in central Asia and subsequently characterize the dataset. Upon completion, these data would then be used as a baseline for a separate study for evaluation, tuning, and enhancement of automatic and interactive processing functions at the IDC. Here, we focused on (1) the location of all local and regional seismic events observed on the three stations of interest, including events located using only a single station; (2) identification of seismic sources routinely observed at each station; (3) background noise characterization; and (4) identification of waveform characteristics including any biases in station azimuth, time, and slowness, etc. Additionally, during this project, notes were kept on the thresholds necessary at each station for a given event to be recorded at one of the other stations, trends in azimuth and velocity (slowness), optimal filter bands for analysis, and any timing errors.

RESEARCH ACCOMPLISHED

Identification of Sources of Observed Seismic Activity

The first objective of this project was a four-month study period to locate all conceivable seismic events (including single station events) observable on three central Asian IMS seismic array stations: Makanchi, Kazakhstan (MKAR); Songino, Mongolia (SONM); and Borovoye, Kazakhstan (BVAR). Routine IDC analysis processing software, related configuration parameters, and database tables including automated seismic detections and events were provided. A total of 120 days of data were reviewed (July 20–October 17, 2006; January 1–30, 2007). The IDC provided dataset consisted of 364 seismic events (epicentral distance to one of the three stations <20°) with 9,566 associated detections. Data analysis for this study was performed by displaying the waveforms in a 5-minute window and manually scrolling page by page. In most cases, waveform filtering was performed on a nearly constant basis. Analyst Review Station (ARS) was the primary tool used for waveform review, phase identification, and location purposes. For routine frequency-wavenumber (F-K) processing, XfkDisplay and the multiband F-K module from the program Geotool were used. The surface solution from the location program was used when only one station observed the events. Geotool was used for spectral analysis and mapping of the clusters of seismic activity.

Over 9,000 events with at least one of the three stations at an epicentral distance <20° were located in the 4-month dataset (Figure 1). About 6% of the located events included arrival times from all three stations, while about 16% included data from at least two stations. Analyst review resulted in the location of 8,752 additional seismic events with 17,043 additional associated arrivals.
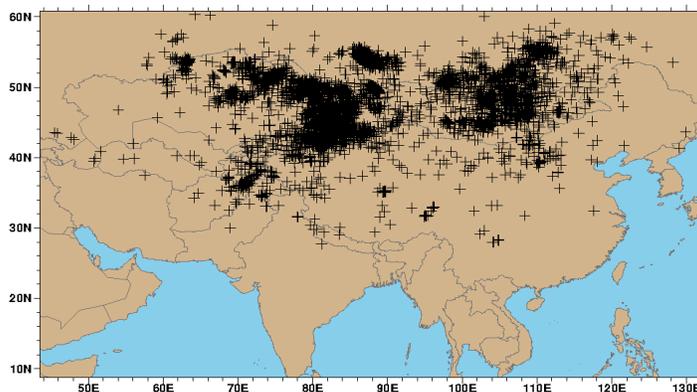

Figure 1. Map showing the location of 9,116 seismic events (crosses) located during this study.

Thirty-nine event clusters (both natural and man-made), based on geographic and temporal distribution, were identified (Figure 2; Table 1). The cluster definition was somewhat arbitrary and in general the size of the cluster area increases as a function of distance from the primary observing station. Of these clusters, 21 are proposed to be mining-related activity and 18 are proposed to be natural seismic activity. Attributes used to characterize clusters were temporal distribution, publicly available imagery, and waveform characteristics. We note that the clusters were

identified based on the seismic event distribution observed in the dataset from July 20–October 17, 2006, and that we did not attempt to identify new clusters in the smaller dataset from January 1–30, 2007.
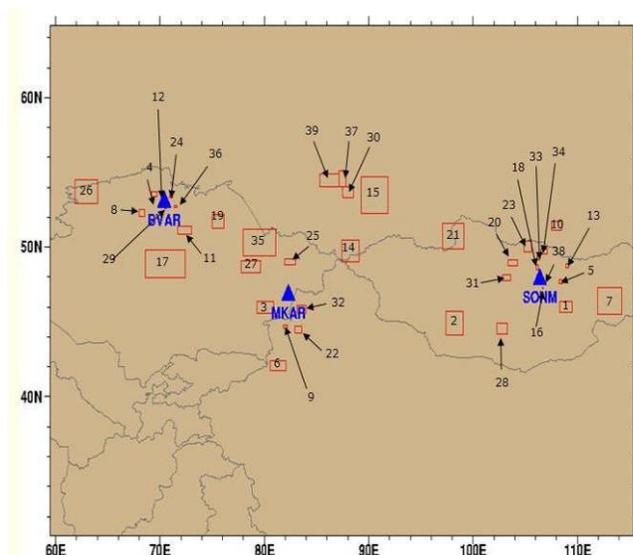

Figure 2. Map of identified seismic event clusters (numbered boxes; numbers correspond to cluster number listed in Table 1) and the location of three IMS seismic stations.

Table 1. Identified Seismic Clusters			
Cluster #	Count	Cluster #	Count
1	72	21	236
2	23	22	51
3	38	23	25
4	26	24	29
5	67	25	39
6	2882	26	46
7	17	27	33
8	10	28	79
9	35	29	25
10	52	30	175
11	29	31	43
12	15	32	16
13	7	33	27
14	123	34	10
15	42	35	182
16	9	36	47
17	80	37	67
18	45	38	5
19	189	39	165
20	49		

For each identified cluster, a brief discussion of the distinguishing characteristics of the seismic events was prepared. This included a table of seismic phase characteristics such as average time and azimuth residuals, average azimuth and slowness, and a plot of typical waveforms (Figure 3) for a representative event in the cluster. Histograms showing the time-of-day and day-of-week patterns were also prepared (Figure 4). Space limitations of this paper prevent providing characteristic summaries for all of the clusters. We present data from two clusters (Table 1, Clusters #5 and #6) here as representative of our findings.

Cluster 5 is located near Baga Nur, Mongolia, in an area of active surface mining. Table 2 shows the average time and azimuth residuals, average azimuth, slowness, and velocity for the 67 events in this cluster. F-K results were consistent, with the exception of Rg, possibly due to mixing with Sn phases. These events occur before the Pn/Pg crossover distance but all regional phases are present. Infrasound arrivals from IMS station I34MN were identified for several of these events. Cluster 6 is located in western China, ~150 km east of the border junction of China, Kazakhstan, and Kyrgyzstan, an active area of natural seismicity. Table 3 shows the average time and azimuth residuals, average azimuth, slowness, and velocity for the 2882 events in this cluster. Sn was the most prominent phase observed on MKAR for this set of earthquakes. In addition to the 2882 located events, countless other "lone Sn" events without discernable P-type phases were observed. The waveforms from this cluster are very similar amongst the numerous events and would be good candidates for waveform correlation analysis, which is beyond the scope of this study. A dominant noise source on station MKAR can be problematic for phase identification.

Table 2. Phase-Specific Residuals for Cluster 5

Station	Phase	Count	Av. Time Res. (sec) ± 1 SD	Av. Azimuth (deg) ± 1 SD	Av. Azimuth Res. (deg) ± 1 SD	Av. Slowness (sec/deg) ± 1 SD	Av. Velocity (km/sec)
SONM	Pg	65	−0.66 ± 0.19	94.92 ± 2.66	−0.40 ± 2.66	17.46 ± 1.01	6.37
SONM	Pn	65	0.58 ± 0.26	96.82 ± 1.76	1.47 ± 1.76	14.52 ± 3.11	7.66
SONM	Lg	61	−0.42 ± 0.27	95.57 ± 1.89	0.25 ± 1.89	27.81 ± 2.01	4.00
SONM	Sn	65	1.56 ± 0.70	95.44 ± 1.66	0.08 ± 1.66	24.07 ± 1.15	4.62
SONM	Rg	39	3.93 ± 1.93	94.03 ± 5.03	−0.79 ± 5.03	26.84 ± 5.30	4.14

Table 3. Phase-Specific Residuals for Cluster 6

Station	Phase	Count	Av. Time Res. (sec) ± 1 SD	Av. Azimuth (deg) ± 1 SD	Av. Azimuth Res. (deg) ± 1 SD	Av. Slowness (sec/deg) ± 1 SD	Av. Velocity (km/sec)
MKAR	Pn	2501	0.00 ± 0.35	191.36 ± 5.10	2.08 ± 5.10	13.26 ± 1.63	8.39
MKAR	Pg	1960	−0.72 ± 0.75	192.21 ± 4.62	1.97 ± 4.62	15.61 ± 1.36	7.12
MKAR	Sn	2871	2.29 ± 0.74	185.95 ± 3.08	−3.55 ± 3.08	23.93 ± 0.89	4.65
MKAR	Lg	2722	−1.51 ± 0.54	194.07 ± 3.64	4.45 ± 3.64	28.67 ± 1.63	3.88
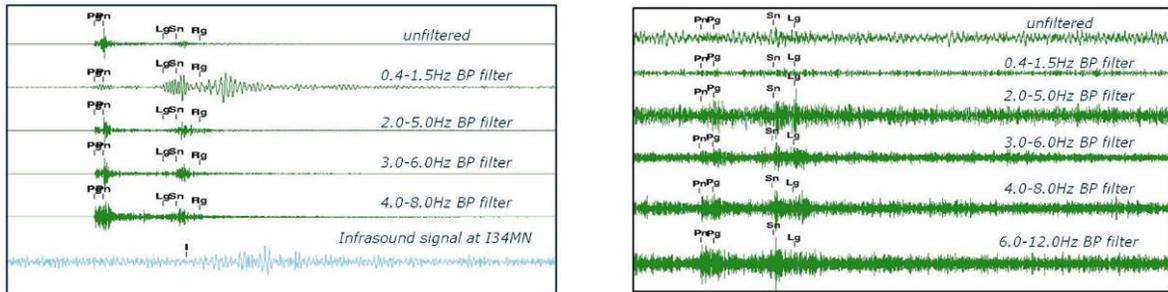
Figure 3: Typical waveforms from seismic events in Cluster 5 (left) and Cluster 6 (right).
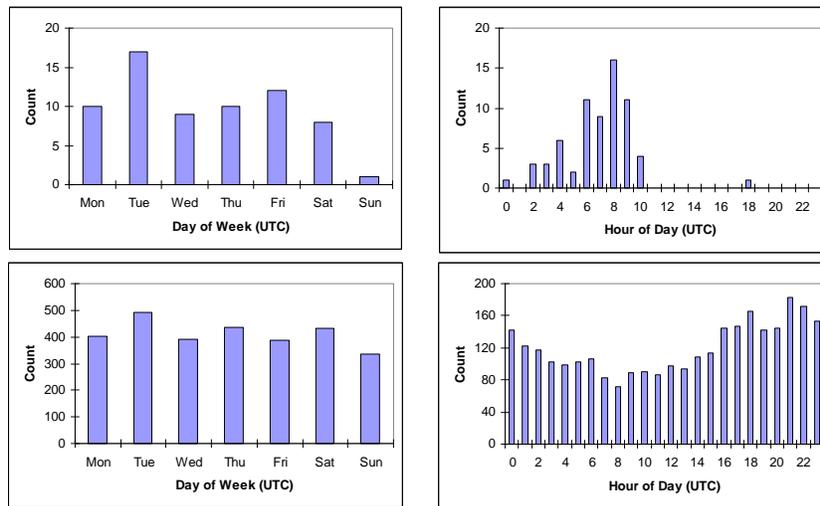
Figure 4. Histograms of day of week and time of day for Cluster 5 (top) and Cluster 6 (bottom).

Station-Specific Observations

In this section, we present observations on characterization of the background noise, identification of waveform characteristics including any biases in station azimuth, time, and slowness, etc., for each of the three stations studied.

MKAR (Makanchi, Kazakhstan) Array

In 2005, the IDC associated initial P-type arrivals from station MKAR with approximately 50% of Reveiwed Event Bulletin (REB) events (13,312 of 26,852). Signals are observed across the spectrum from low-frequency teleseismic to very high frequency local and regional events. A 2–5-Hz bandpass causal Butterworth filter was the primary filter used during the analysis of the July–October 2006 dataset. For the January 2007 dataset, a 1.5–3.0-Hz bandpass causal Butterworth filter was sufficient for observation of all seismic phases. Extremely high frequency events are commonly observed on MKAR waveforms, necessitating use of a suite of bandpass filters. Events from the southeast in an azimuth range between 110° and 140° possess very high frequency, sharp, clear Pn phases with high P/S ratios. Events located east of 95° east longitude have greatly attenuated S-type phases. For all seismic phases,

higher-than-expected velocities were observed from events located to the northwest. For local events (Δ <5°) location, a signal-to-noise ratio (SNR) >20 is typically required for 2+ station locations and an SNR >50 is needed for 3+ station locations. A prominent, intermittent noise source with a center frequency of 4.25 Hz was observed periodically (Figure 5, left).
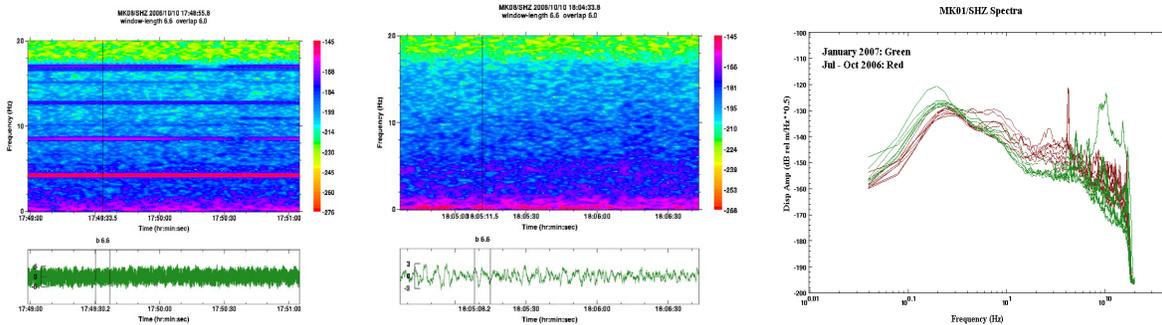

Figure 5. Spectrograms of the element MK08 SHZ showing presence of persistent noise (left) and same element during a time period when the noise was absent (middle) and comparison of spectra from element MK01 SHZ during the two study periods (right).

Figure 6 shows time residuals versus azimuth of each prominent regional phase observed at MKAR. Figure 7 shows azimuth residuals versus azimuth for each regional phase and Figure 8 shows velocity for the same phases.
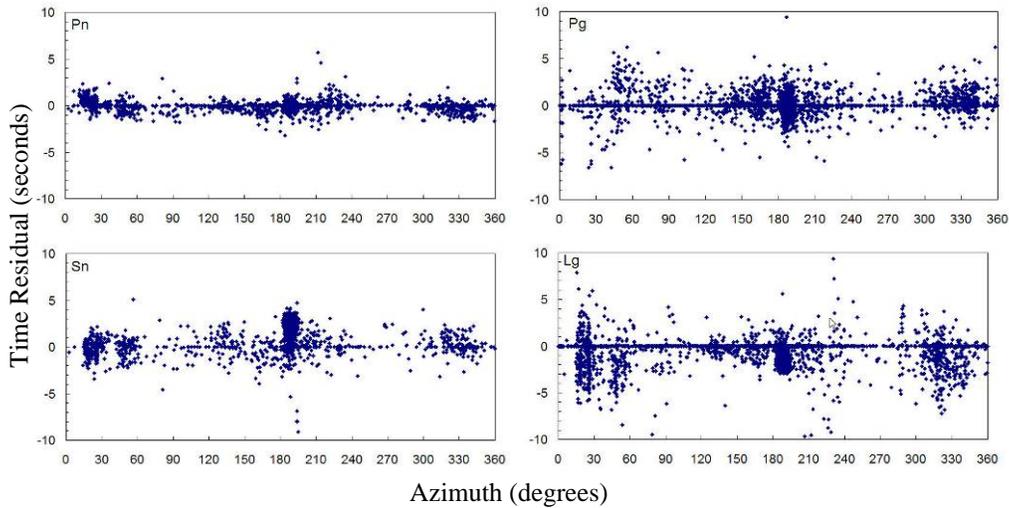
Figure 6. Scatter plots of time residuals versus azimuth for each regional seismic phase observed at station MKAR for the combined datasets.
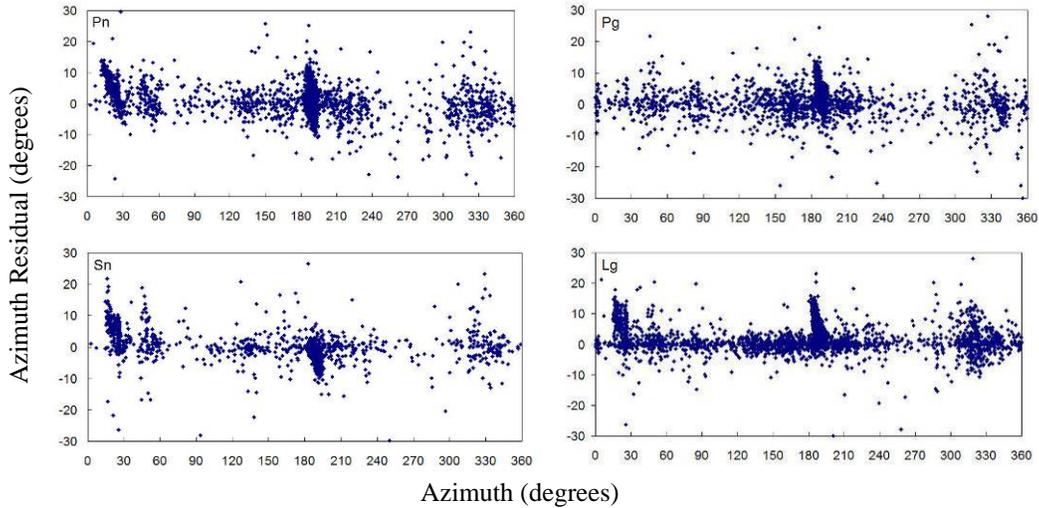
Figure 7. Scatter plots of azimuth residuals versus azimuth for each regional seismic phase observed at station MKAR for the combined datasets.
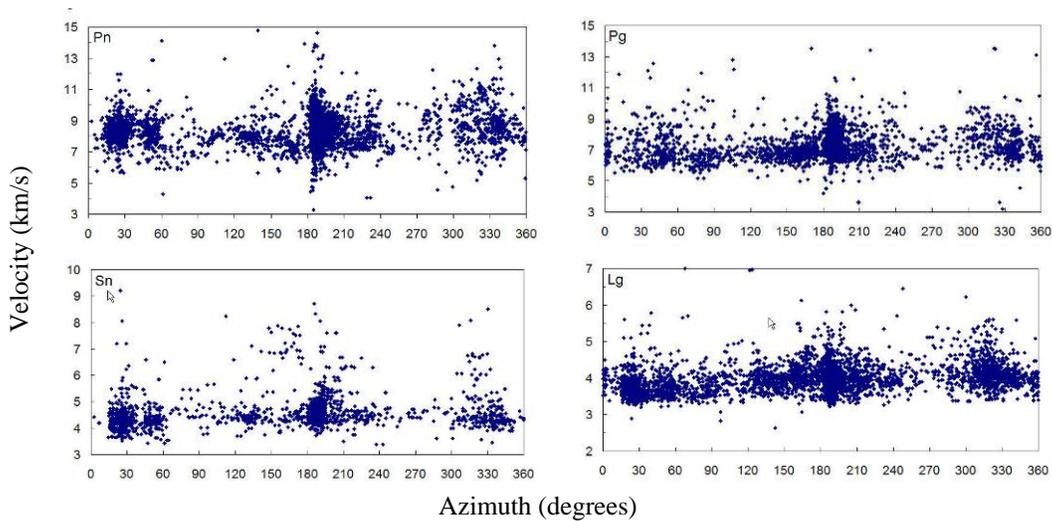
Figure 8. Scatter plots of velocity versus azimuth for each regional seismic phase observed at station MKAR for the combined datasets.

SONM (Songino, Mongolia) Array

In 2005, the IDC associated initial P-type arrivals from station SONM to approximately 56% of REB events (15,049 of 26,852). These statistics are partially misleading due to the large number of aftershocks following the December 26, 2004, Banda Aceh earthquake. For a more realistic assessment, initial P arrivals from station SONM contributed to 9,055 of 25,449 (35.6%) events in 2004. Local events are best observed with lower frequency filters (0.8–3.0 Hz) unless originating from the southwest. Lg arrivals from the north (290°–85° azimuth) often cannot be associated with P-type phases on station SONM. For local events (Δ <5°), an SNR >5 is typically required for 2+ station locations and SNR >120 is needed for 3+ station locations. During the study period, SONM exhibited random noise bursts on elements, predominantly on element SONA0 and its near neighbors in the array. The noise often looks like a seismic event with what appear to be clear P and S arrivals. An attempt to perform F-K analysis or polarization and achieve consistent results on these occurrences was nearly impossible. Figure 9 shows an example of one of these noise bursts.
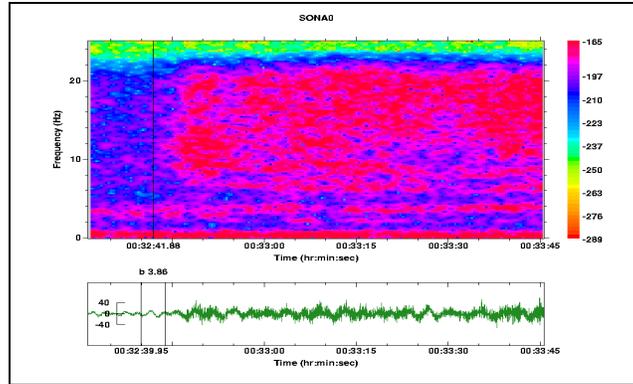
Figure 9: SONA0 spectrogram for shown waveform.

Figure 10 shows time residuals versus azimuth of each prominent regional phase observed at SONM. Figure 11 shows azimuth residuals versus azimuth for each regional phase, and Figure 12 shows velocity for the same phases.
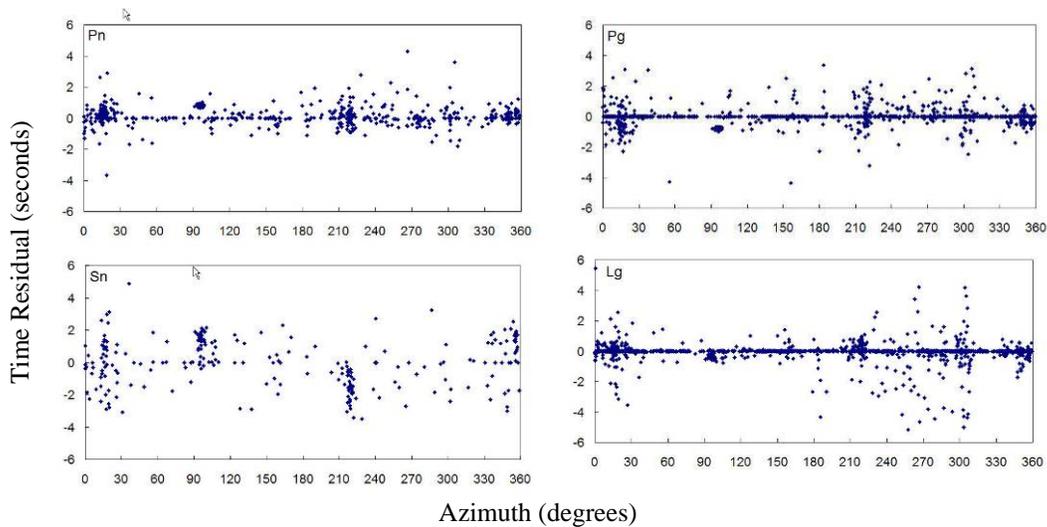

Figure 10. Scatter plots of time residuals versus azimuth for each regional seismic phase observed at station SONM for the combined datasets.
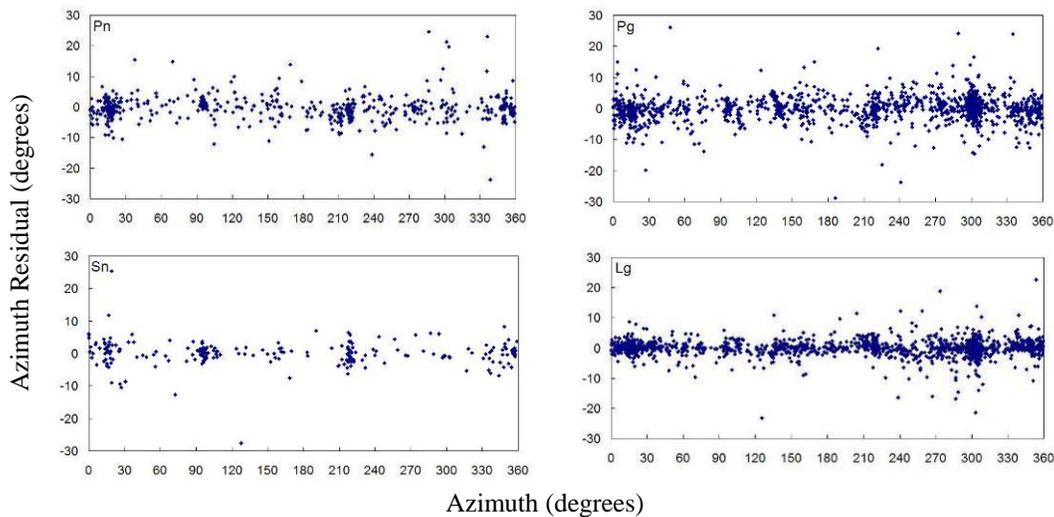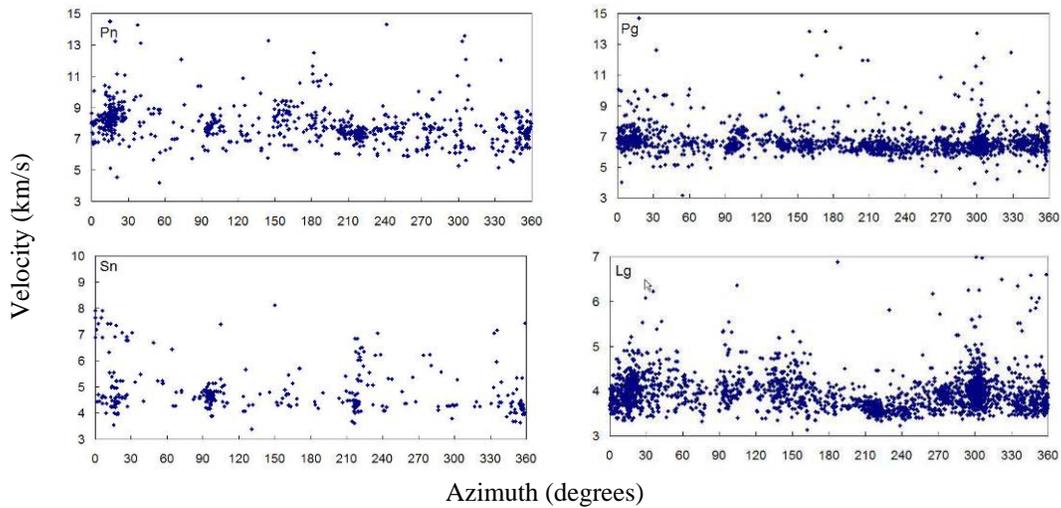

Figure 11. Scatter plots of azimuth residuals versus azimuth for each regional seismic phase observed at station SONM for the combined datasets.

Figure 12. Scatter plots of velocity versus azimuth for each regional seismic phase observed at station SONM for the combined datasets.

BVAR (Borovoye, Kazakhstan) Array

In 2005, the IDC associated initial P-type arrivals from station BVAR to approximately 37% of REB events (9,997 of the 26,852). These statistics are not a full accounting of the station's contribution since it is not a primary station. Application of a 1–5 Hz causal Butterworth filter gave the best presentation of the data while preserving signal content from common events. Extremely high frequency events are common from only a few azimuths. BVAR was relatively free of random noise bursts as seen at station SONM. All regional phases have an azimuth residual 10°–15° degrees less than calculated station to event azimuth for events originating in the Hindu Kush area. For local events (Δ <5°), an SNR >10 is typically required for 2+ station locations and no 3+ station events were observed in the study dataset. A lower-frequency monochromatic ring (Figure 13) affected F-K analysis periodically. BVA0's east trace (BHE) was inoperative for the entirety of the analysis period.
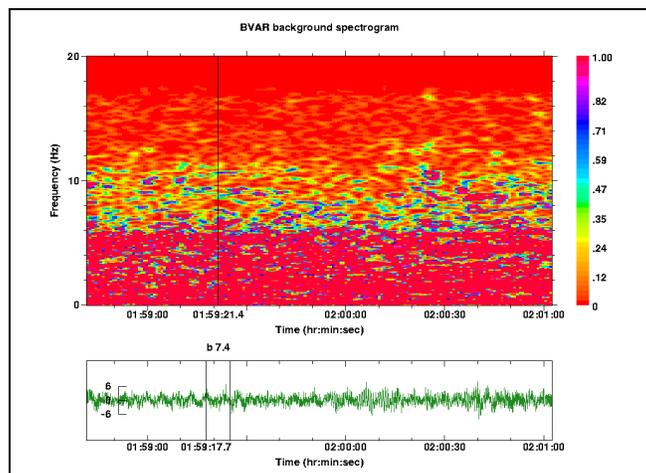

Figure 13. Spectrum and spectrogram of the monochromatic background. The peak between 1 and 2 Hz complicates analysis since it is in the prominent band for signal observation.

Figure 14 shows time residuals versus azimuth of each prominent regional phase observed at BVAR. Figure 15 shows azimuth residuals versus azimuth for each regional phase and Figure 16 shows velocity for the same phases.
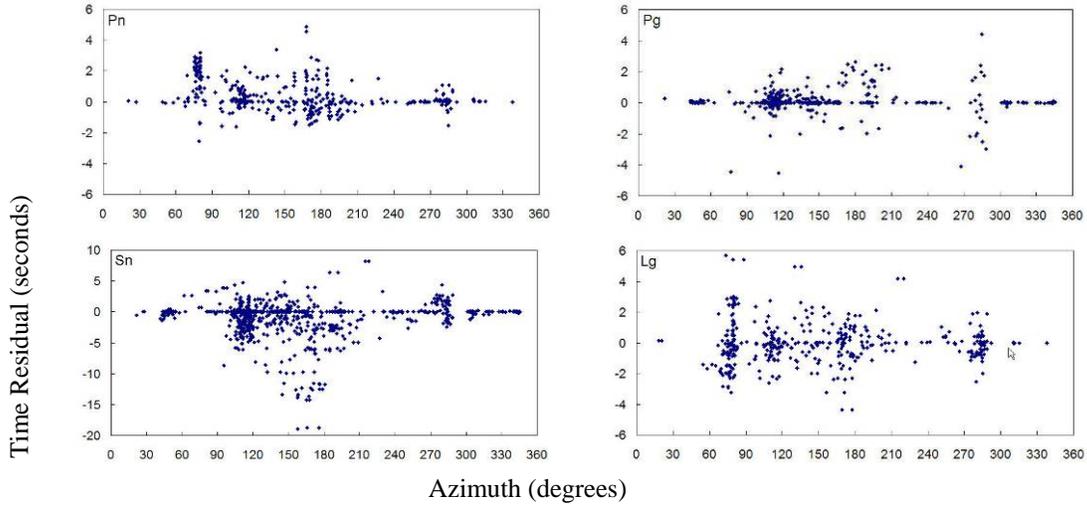
Figure 14. Scatter plots of time residuals versus azimuth for each regional seismic phase observed at station BVAR for the combined datasets.
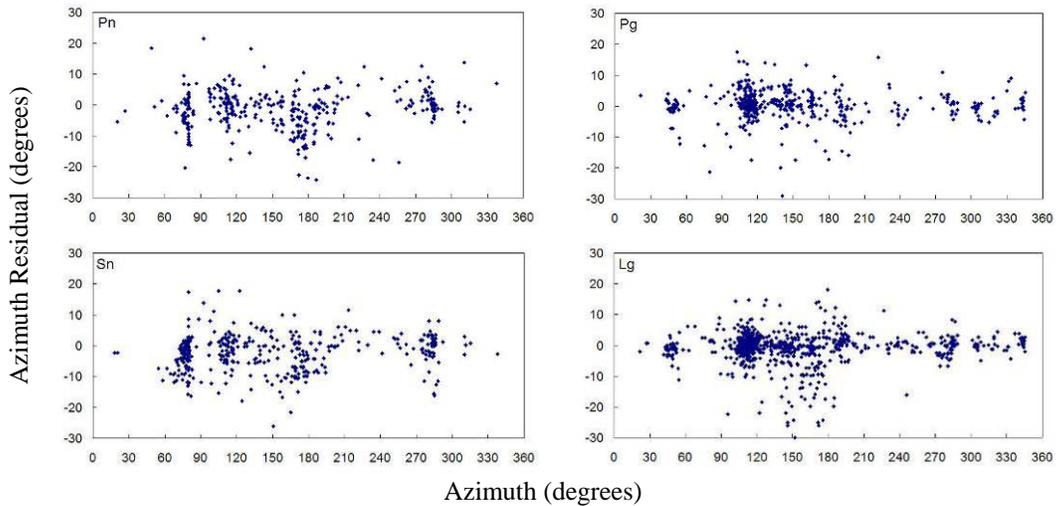

Figure 15. Scatter plots of azimuth residuals versus azimuth for each regional seismic phase observed at station BVAR for the combined datasets.
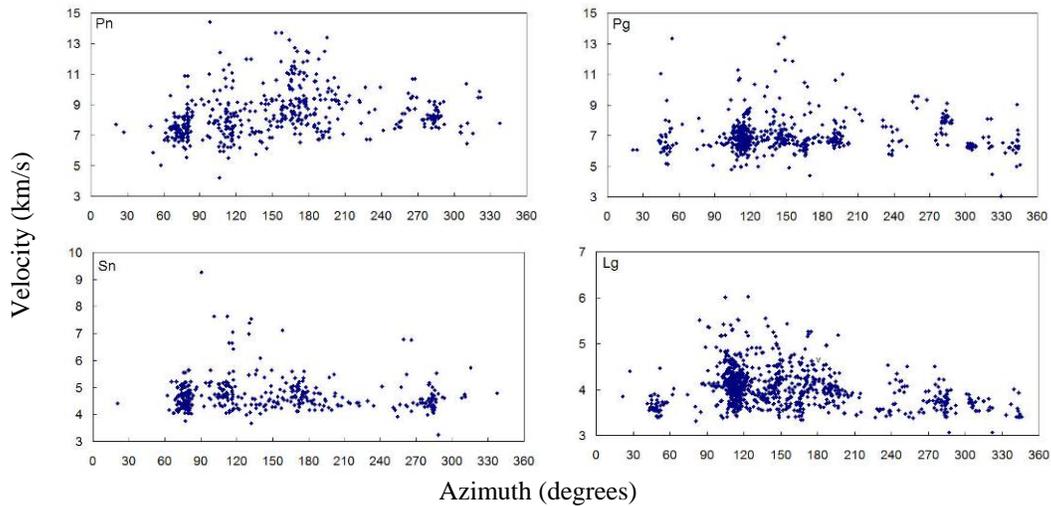

Figure 16. Scatter plots of velocity versus azimuth for each regional seismic phase observed at station BVAR for the combined datasets.

CONCLUSIONS AND RECOMMENDATIONS

Over 9,000 events with at least one of the three IMS stations MKAR, SONM, and BVAR, located at an epicentral distance less than 20° were human-analyst reviewed, including phase identification and event location. About 6% of the located events included arrival times from all three stations, while about 16% included data from at least two stations. Thirty-nine event clusters, based on geographic and temporal distribution, were identified.

The three stations MKAR, SONM, and BVAR are all high-quality seismic arrays. Periodic noise on these stations affects phase identification. The most-prominent features of the dataset that impact routine analysis include the following observations. On station MKAR, regional phases from events located northwest of the station have F-K velocities much higher than are expected. On station SONM large numbers of "lone Lg" phases with no corresponding P-type phases are observed. Regional seismic phases observed on station BVAR from events located in the Hindu Kush area have an azimuth residual 10°–15° less than calculated station to event azimuth. The best frequency bands for general analysis of these stations are MKAR 2–5 Hz, SONM and BVAR 1–5 Hz. For the smaller events, manipulation of default F-K parameters is often necessary.

The final product of this study will provide a benchmark data baseline from which to tune automatic processes.

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